Groundwater and Terrestrial Water Storage

section for BAMS "State of the Climate in 2011"

Matthew Rodell, Don P. Chambers, and James S. Famiglietti

Most people think of groundwater as a resource, but it is also a useful indicator of climate variability and human impacts on the environment. Groundwater storage varies slowly relative to other non-frozen components of the water cycle, encapsulating long period variations and trends in surface meteorology. On seasonal to interannual timescales, groundwater is as dynamic as soil moisture (Rodell and Famiglietti, 2001; Alley et al., 2002), and it has been shown that groundwater storage changes have contributed to sea level variations (Milly et al., 2003; Wada et al., 2010).

Groundwater monitoring well measurements are too sporadic and poorly assembled outside of the United States and a few other nations to permit direct global assessment of groundwater variability. However, observational estimates of terrestrial water storage (TWS) variations from the GRACE satellites (see sidebar, [page ##]) largely represent groundwater storage variations on an interannual basis, save for high latitude/altitude (dominated by snow and ice) and wet tropical (surface water) regions (Rodell and Famiglietti, 2001).

Figure 1 maps changes in mean annual TWS from 2009 to 2010, based on GRACE, reflecting hydroclimatic conditions in 2010. Severe droughts impacted Russia and the Amazon, and drier than normal weather also affected the Indochinese peninsula, parts of central and southern Africa, and western Australia. Groundwater depletion continued in northern India (Rodell et al., 2009; Tiwari et al., 2009), while heavy rains in California helped to replenish aquifers that have been depleted by drought and withdrawals for irrigation, though they are still below normal levels (Famiglietti et al., 2011). Droughts in northern Argentina and western China similarly abated. Wet weather raised aquifer levels broadly across western Europe. Rains in eastern Australia caused flooding to the north and helped to mitigate a decade long drought in the south. Significant reductions in TWS seen in the coast of Alaska and the Patagonian Andes represent ongoing glacier melt, not groundwater depletion.

Figures 2 and 3 plot time series of zonal mean and global GRACE derived non-seasonal TWS anomalies (deviation from the mean of each month of the year) excluding Greenland and Antarctica. The two figures show that 2010 was the driest year since 2003. The drought in the Amazon was largely responsible, but an excess of water in 2009 seems to have buffered that drought to some extent (Figure 2). The drying trend in the 25-55°S zone is a combination of Patagonian glacier melt and drought in parts of Australia.

References

Alley, W. M., R. W. Healy, J. W. LaBaugh, and T. E. Reilly, Flow and storage in groundwater systems, Science, 296, 1985-1990, 2002.

Famiglietti, J. S., M. Lo, S. L. Ho, J. Bethune, K. J. Anderson, T. H. Syed, S. C. Swenson, C. R. de Linage, and M. Rodell, 2011: “Satellites measure recent rates of groundwater depletion in California's Central Valley.” Geophysical Research Letters, 38 –(DOI http://dx.doi.org/10.1029/2010GL046442.

Milly, P. C. D., A. Cazenave, and M. C. Gennero, Contribution of climate-driven change in continental water storage to recent sea-level rise, Proceedings of the National Academy of Sciences, 100(23), 13158-13161, 2003.

Rodell, M., and J. S. Famiglietti, An analysis of terrestrial water storage variations in Illinois with implications for the Gravity Recovery and Climate Experiment (GRACE), Wat. Resour. Res., 37, 1327-1340, 2001.

Rodell, M., I. Velicogna, and J.S. Famiglietti, Satellite-based estimates of groundwater depletion in India, Nature, 460, 999-1002, doi:10.1038/460789a, 2009.

Tiwari, V. M.; Wahr, J.; Swenson, S. 2009: Dwindling groundwater resources in northern India, from satellite gravity observations. Geophysical Research Letters 36 - L18401 (DOI http://dx.doi.org/10.1029/2009GL039401).

Wada, Y., L. P. H. van Beek, C. M. van Kempen, J. W. T. M. Reckman, S. Vasak, and M. F. P. Bierkens (2010), Global depletion of groundwater resources, Geophys. Res. Lett., 37, L20402, doi:10.1029/2010GL044571.

Figures

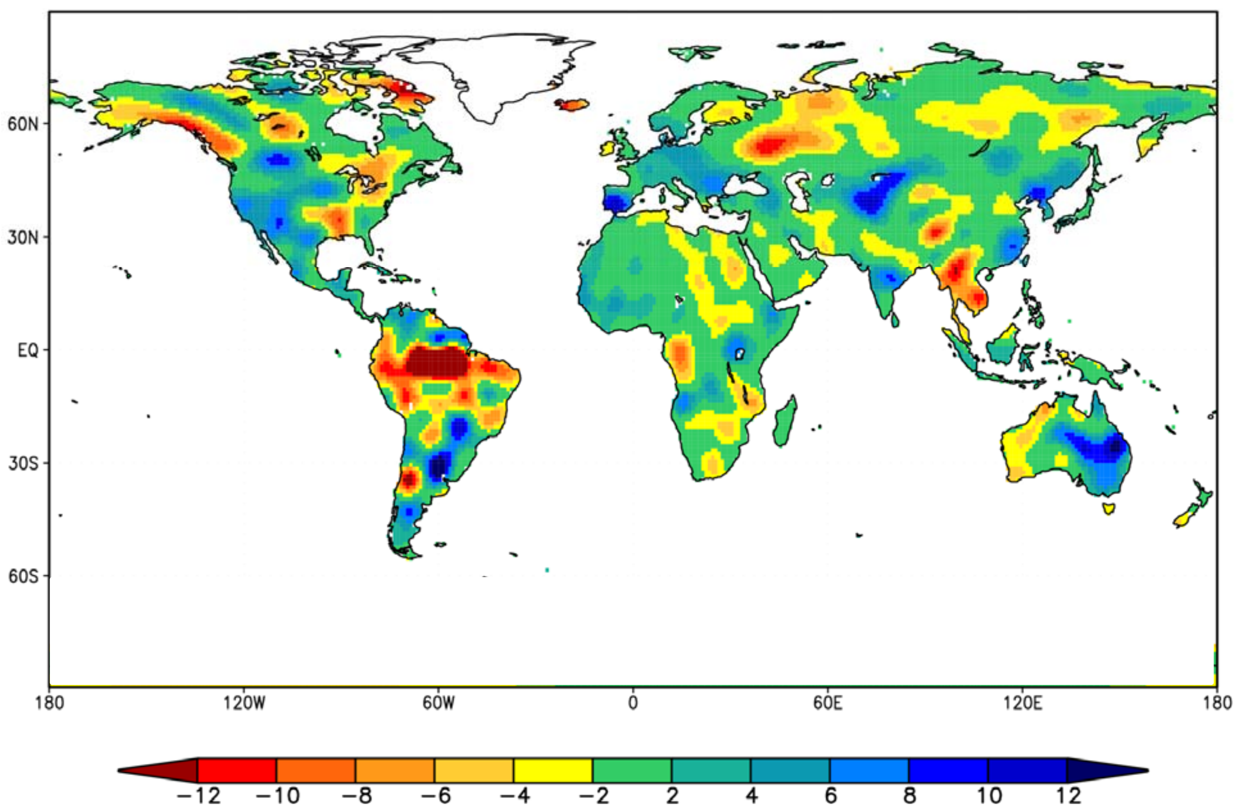

Figure 1. Changes in annual-mean terrestrial water storage (the sum of groundwater, soil water, surface water, snow, and ice, as an equivalent height of water in cm) between 2009 and 2010, based on GRACE satellite observations.

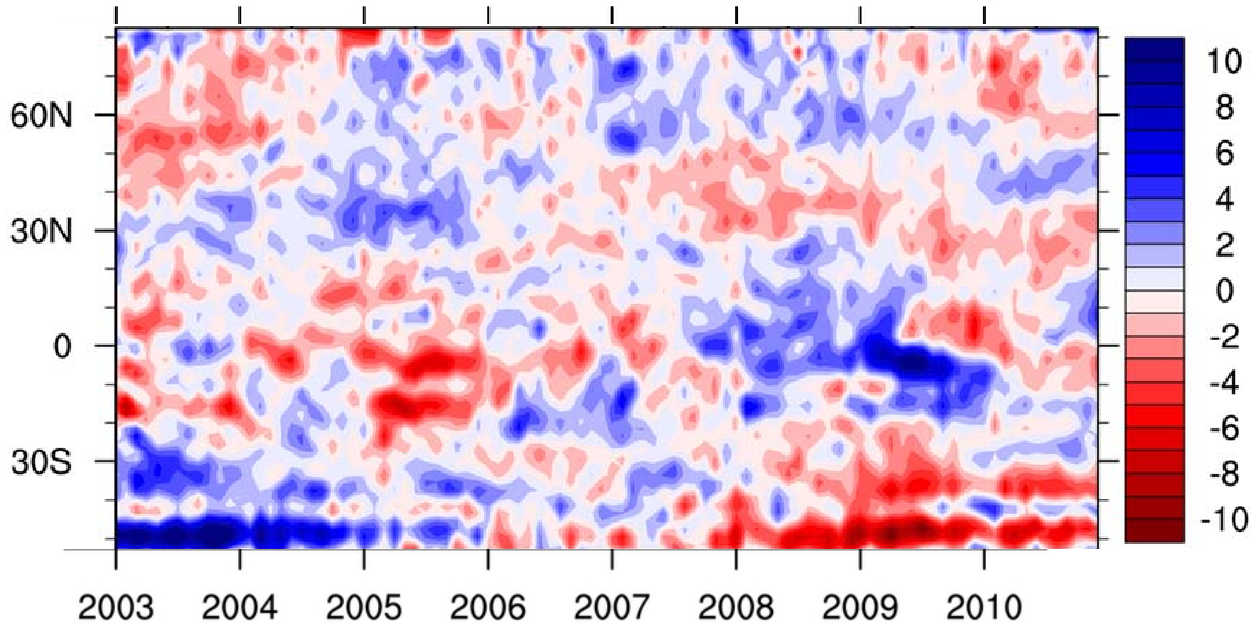

Figure 2. As for Fig. 2.1 but for terrestrial water storage anomalies in cm equivalent height of water (reference period 2003-2007).

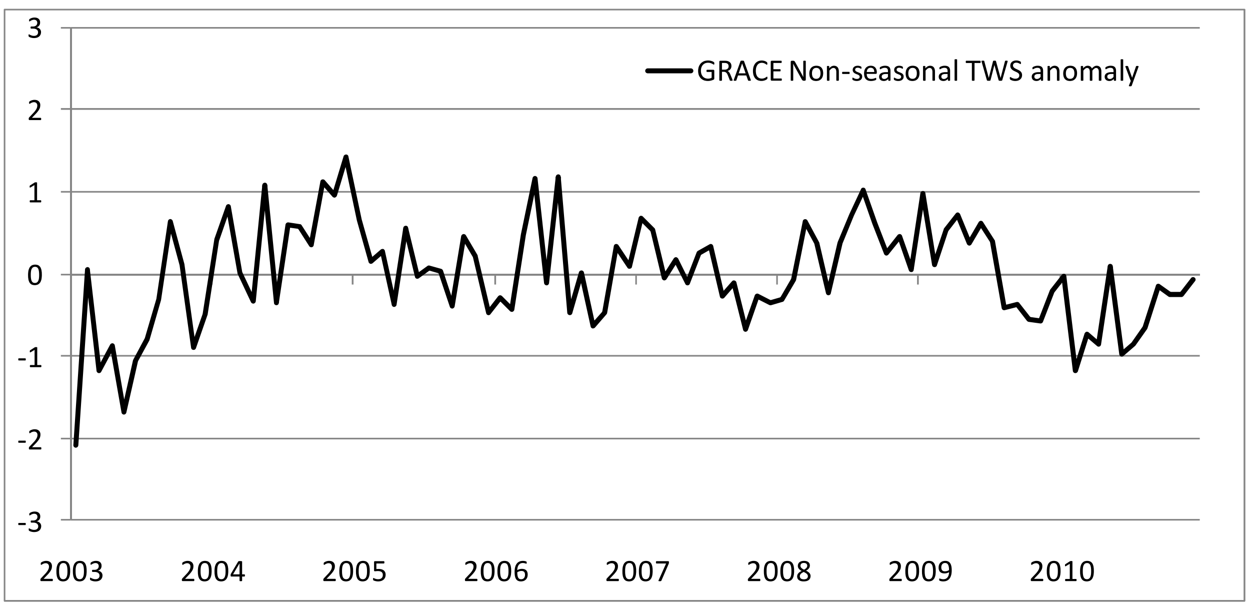

Figure 3. As for Figure 2.2 but for terrestrial water storage anomalies in cm equivalent height of water.